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THE CONVERGENCE OF SKIN AND RECTAL TEMPERATURES AS A CRITERION FOR HEAT TOLERANCE

Kent B. Pandolf and Ralph F. Goldman

U.S. Army Research Institute of Environmental Medicine
Natick, Massachusetts 01760 USA

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Many laboratories (1,2,3) use criteria of a rectal temperature (T_{re}) of $39.5 \pm 0.5^{o}C$ and/or heart rate (HR) of 180 beats/min ± 10% as tolerance limits for men working in the heat. In earlier work from this laboratory, we suggested that the mean skin temperature ($\bar{T}_{sk}$) 10 minutes into the exposure was a prognosticator of the tolerance time for men working in hot environments (4). More recently, having acquired the ability to simultaneously plot both rectal and mean skin temperature on line during experimentation, for each subject, we have been impressed with the extent to which convergence of $\bar{T}_{sk}$ toward T_{re} indicates a decreasing tolerance time; indeed, we have already suggested that where the difference between skin and rectal temperatures approached $1^{o}C$, tolerance time would be acutely limited (4). The present manuscript reports data from two recent investigations in which the observed convergence of $\bar{T}_{sk}$ on T_{re} proved to be a very reliable indicator of tolerance limits for individual subjects, although T_{re} and HR were generally well below levels normally associated with tolerance limitation. Subsequent analysis suggests that tolerance time can be quite accurately estimated from a prediction of convergence.

METHODS

Both studies (S_1 and S_2) involved young, fit soldiers, with 5 to 7 days of heat acclimatization, who volunteered to participate in evaluations of new clothing. In S_1, 7 subjects (25 yr, 178 cm, 77 kg) performed mild exercise (120 min) in impermeable clothing in hot-dry ($46^{o}C$, 10% rh) and hot-wet ($35^{o}C$, 75% rh) environments with a 1.1 m/s wind and radiant load of 0.11 Watt/cm^2. Metabolic heat load of this mild exercise plus an adjustment for solar heat load incurred was estimated to have averaged 225 Watt. In S_2, 6 semi-permeable systems were evaluated ($49^{o}C$, 20% rh) while 6 subjects (20 yr, 174 cm, 67 kg) attempted a 50 min walk (1.34 m/s) followed by a 30 min rest. Physiological measurements included T_{re}, $\bar{T}_{sk}$, HR and sweat rate. During both studies (S_1 and S_2), mean skin and rectal temperatures were plotted for each subject at approximate 2 min intervals, using a Hewlett Packard 9810 Calculator and 9862A Plotter for on-line data presentation.

RESULTS AND DISCUSSION

In the present study (S_1, hot-dry phase), convergence of $\bar{T}_{sk}$ and T_{re} was associated with early voluntary termination (mean ± SE = 36.5 ± 3.81 min) with substantial subjective distress although mean (±SE) T_{re} ($38.3 \pm 0.19^{o}C$) and HR (142 ± 9.9 beats/min) were well below usual tolerance levels. In the hot-wet phase (S_1), the mean final T_{re} for these subjects was $38.7 \pm 0.24^{o}C$, HR was 166 ± 6.1 beats/min, while the average work time was 64.5 ± 5.31 min. In S_2, exposures were terminated (mean = 33.7 ± 1.25 min), upon convergence of $\bar{T}_{sk}$ on T_{re}, at near collapse levels despite mean T_{re} of $38.4 \pm 0.09^{o}C$ and HR of 166 ± 5.8 beats/min. During all of these exposures, the individual $\bar{T}_{sk}$ rose rapidly and quite linearly (r = 0.90 - 0.99).

Our laboratory, and many others, have used physiological criteria of a T_{re} of 39.5 ±0.5°C and/or HR of 180 beats/min ± 10%, or use subjective criteria involving motivation or a voluntary statement of exhaustion as the tolerance limits for men working in the heat. Unfortunately, these criteria, particularly from a physiological standpoint, evolved from experimentation involving lightly clothed or seminude subjects generally evaluated in hot-dry environments. These criteria appear realistic for these conditions because enhanced evaporative cooling generally maintains a lower $\bar{T}_{sk}$ so that heat exhaustion results primarily from elevated T_{re} as heat is stored in the core. However, working in hot and humid external environments or in semi-permeable or impermeable clothing systems with hot-humid internal conditions, alters evaporative cooling and these generally used tolerance criteria appear to need modification to safeguard the subjects in a hot-wet microclimate, perhaps adding a convergence criterion.

The establishment of safe exposure limits or estimated tolerance times to severe heat exposure has taken two directions. Some (5,6) have utilized weighted environmental temperature scales (dry and wet bulb temperatures) to relate safe exposure times to an index of climatic severity. Others (2,4,7) have pursued the possibility of using a single physiological measure to predict tolerance time in thermally severe environments. When evaporative cooling is limited, as it is in many severe heat exposures, $\bar{T}_{sk}$ is directly influenced by ambient temperature. Thus, tolerance time has been somewhat accurately estimated from the 10-min $\bar{T}_{sk}$ (2,4,7). However, neither approach considers individual variation to any great degree (i.e., level of physical fitness, state of acclimatization); the effects of different work levels, clothing, equipment and other factors of performance time tend also to be ignored.

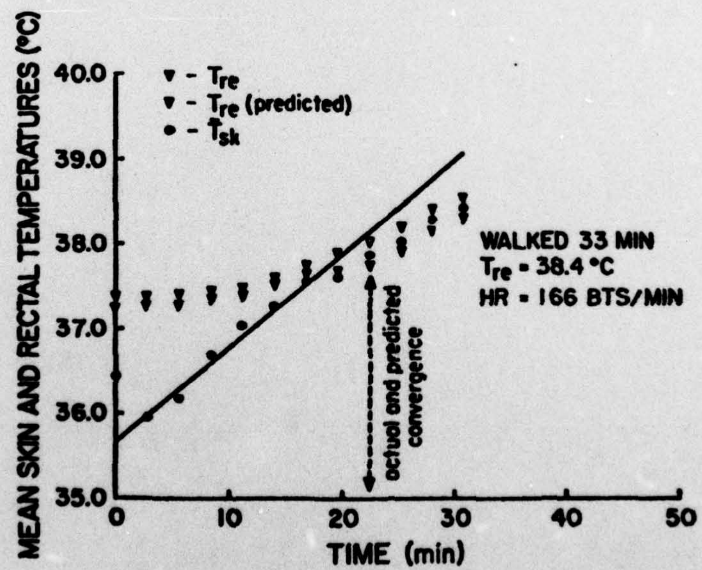

Fig. 1. Predicted and observed convergence of mean skin ($\bar{T}_{sk}$) and rectal (T_{re}) temperatures (°C) used to determine an individual's tolerance limit. Predicted T_{re} computed according to Givoni and Goldman (8); linear regression of $\bar{T}_{sk}$ calculated by least squares method (r = 0.98).

When rectal and skin temperatures converge during work in the heat, core to skin conductance drops, heart rate increases rapidly and heat exhaustion is imminent. While the individual experimental exposure time to produce full convergence of $\bar{T}_{sk}$ on T_{re} varied from 25 to 65 min, convergence time could be quite accurately predicted (accuracy of ±5 min) well before its actual occurrence. This approach for predicting safe exposure and tolerance time while working in heat when evaporative cooling is greatly reduced has many advantages. First, individual differences will be minimized because each individual will act as his own control. Prior to such exposures, T_{re} can be predicted quite accurately (8) for a fit, young man considering such factors as height, weight, metabolic rate, external load, clothing characteristics (clo, i_m/clo), wet and dry bulb temperatures, wind velocity and state of acclimatization to mention only some of the variables; factors to adjust for sex, age and level of fitness (cardiorespiratory) are being developed for this approach. Linear regression of the initial $\bar{T}_{sk}$ can be accurately extrapolated to intersect the previously plotted, individually predicted T_{re} response. This approach for predicting the convergence of $\bar{T}_{sk}$ on T_{re} and the individual tolerance limits expected while working in the heat in semi-permeable or impermeable clothing is displayed in Fig. 1. Thus, a predicted tolerance time based on convergence of $\bar{T}_{sk}$ on T_{re} would be available far in advance of the actual convergence. The apparent advantages of this technique compared to using either a single physiological measure such as $\bar{T}_{sk}$ or a weighted environmental temperature scale are obvious. The use of this proposed safeguard criteria for human experiments in severe heat should help prevent heat illness and casualties both in the laboratory and in the field.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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